

A

Appendix A: Definition of Terms

Note: If there is any discrepancy between the definitions in this document and those in the ESCO/federal agency contract, the definitions in the contract prevail.

Baseline Usage or Demand The calculated or measured energy usage (demand) by a piece of equipment or a site prior to the implementation of the project. Baseline physical conditions such as equipment counts, nameplate data, and control strategies will typically be determined through surveys, inspections, and/or metering at the site.

Contract The executed document between a federal agency and the ESCO and any appendices, as amended from time to time, that outline provisions of the project.

Commissioning The process of documenting and verifying through adjusting/remediating the performance of building facility systems so that they operate in conformity with the design intent. An independent party rather than an ESCO may complete system/equipment commissioning. Current editions of the American Society of Heating, Refrigerating, and Air Conditioning Engineers' (ASHRAE) commissioning guideline GPC-1 can be the basis for commissioning activities.

Demand Reduction Estimates Energy demand reductions (e.g., in kW or Btu/hr) determined from metering and/or calculations performed in accordance with the provisions of the federal agencies' approved measurement and verification plans, and documented in regular true-up reports.

Energy Savings Estimates Energy savings (e.g., in kWh or therms) determined from metering and/or calculations performed in accordance with the provisions of the federal agencies' approved measurement and verification plans, and documented in regular interval reports.

Energy Services Company (ESCO) An organization that designs, finances, procures, installs, and possibly maintains one or more ECMs or systems at a federal facility or facilities.

Measurements, Continuous Measurements repeated at regular intervals over the baseline period or contract term.

Measurements, Long-Term Measurements taken over a period of several years.

Measurements, Short-Term Measurements taken for several hours, weeks, or months.

Measurements, Spot Measurements taken one-time; snapshot measurements.

M&V Option One of four generic M&V approaches (A, B, C, and D) defined for ESPC projects. These options are defined in the International Performance Measurement and Verification Protocol (IPMVP) and in Chapter 2 of this document.

M&V Method A generic, non-project-specific M&V approach that applies one of the four M&V Options to a specific ECM technology category. Examples of ECM categories are lighting efficiency retrofits and constant-load motor retrofits.

M&V Technique An evaluation procedure for determining energy and cost savings. M&V techniques discussed in this document include engineering calculations, metering, utility billing analysis, and computer simulation.

Performance Factors Factors that influence energy use (e.g., outdoor air temperature, lighting levels, and timeclock settings).

Performance Period The time period spanning from approval of the project installation to the end of the contract.

Project Pre-Installation Report The initial report that provides a description and inventory of existing and proposed energy-efficiency equipment, estimates of energy savings, and a site-specific M&V plan (if not included in the contract). This report must be received and approved before the installation of energy-efficient equipment or O&M measures can occur.

Project Post-Installation Report The report that provides a description and inventory of baseline and installed energy-efficiency equipment, estimates of energy savings, and M&V results. After the installation of ECMs, the ESCO provides pre-specified documentation that verifies the installed equipment/systems, provides ECM energy saving estimates, and demonstrates proper commissioning has been completed.

Performance Period Energy Use or Demand The calculated energy usage (or demand) by a piece of equipment or a site after implementation of the project. The ESCO and the federal agency verify the post-installation energy use, the installation of the proper equipment components or systems, the correct operation of the components and systems, and their potential to generate the predicted savings.

Project The implementation of energy efficiency services at a federal facility or group of facilities.

Project-Specific M&V Plan Plan providing details on how a specific project's savings will be verified based on the general M&V approaches described in this document.

Regular Interval Report Prespecified documentation provided by the ESCO at defined intervals (e.g., annually) during the performance period but after the submittal of the project post-installation report. This documentation verifies the continued operation of the ECMS, provides the associated energy savings estimates, demonstrates proper maintenance, and provides M&V results. The energy savings documented in the report serves as the basis for the ESCO's invoice after the regular interval report has been reviewed and approved by the federal agency.

Usage Group A collection of equipment (e.g., motors or rooms with light fixtures) with similar characteristics (e.g., operating schedule).

B

Appendix B: Sample Metering Forms

Transducer Installation and Calibration Report Example

Report Date:

I. Site Customer Information

| | |
|------------------------------|--|
| Site Name: | |
| Site Contact/Phone #: | |
| Contractor Company Name: | |
| Contractor Name/Contact: | |
| Installer Company Name: | |
| Installer Name/Phone Number: | |
| Date Installed/Calibrated: | |

II. Transducer

| | | |
|--|---|--------------|
| Flow Meter <input type="checkbox"/> | Temperature Sensor <input type="checkbox"/> | Device ID #: |
| Pulse Generator <input type="checkbox"/> | Status Indicator <input type="checkbox"/> | |
| | Current Transducer <input type="checkbox"/> | |
| Other <input type="checkbox"/> Describe: | | |
| Device Type: | | |
| Variable being measured: | | |
| Expected range of variable (w/units): | | -- |

III. Device Specifications

| | |
|---------------------|----|
| Make: | |
| Model: | |
| Serial #: | |
| Location at site: | |
| Location in system: | |
| Output: | |
| Multiplier: | |
| Precision: | |
| Accuracy: | |
| Range (w/units): | -- |

☐ Include copy of calibration tag
☐ Include specification sheet
☐ Include invoice for device
☐ Attach copy of manual

IV. Calibration Results

| | |
|--------------------|--|
| Method: | |
| Standard used: | |
| Units of readings: | |
| Data logger: | |
| Notes: | |

| Adjustment Iteration | Date | Time | Transducer Reading T | Standard Reading S | T-S | Percent $\frac{T-S}{S}$ | Comments |
|----------------------|------|------|----------------------|--------------------|-----|-------------------------|----------|
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Data Logger Report Example

 Report Date:

I. Site/Installer Information

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|------------------------------|----------------------|
| Site Name: | <input type="text"/> |
| Site Contact/Phone #: | <input type="text"/> |
| Contractor Company Name: | <input type="text"/> |
| Contractor Name/Contact: | <input type="text"/> |
| Installer Company Name: | <input type="text"/> |
| Installer Name/Phone Number: | <input type="text"/> |
| | <input type="text"/> |
| Date Installed/Programmed: | <input type="text"/> |

II. Data Collection Information

| | |
|---|----------------------|
| Data Output Format: | <input type="text"/> |
| | <input type="text"/> |
| Data Reporting Period: | <input type="text"/> |
| Storage Capacity of Data Logger: | <input type="text"/> |
| Downloading Procedure: | <input type="text"/> |
| | <input type="text"/> |
| Person/company responsible for delivering data to federal agency: | <input type="text"/> |

III. Data Format

| Channel | Output | Units | Expected Range | Sampling Rate |
|---------|--------|-------|----------------|---------------|
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IV. Transducers

| Channel | Transducer /Location | Transducer Output | Transducer Vendor/Model | Transducer Install Date | Transducer Calibrated |
|---------|----------------------|-------------------|-------------------------|-------------------------|-----------------------|
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C

Appendix C: Sample Lighting and Motor Survey Forms

Table LE1
Pre-Installation Lighting Equipment Expected to be Installed

Site Name:

Date of Table:

Bidder Name:

Table Completed By:

| Space ID | Circuit ID | Usage area type | Existing Lighting Equipment | | | | | | Proposed Lighting Equipment | | | | | Space heated and/or cooled | Notes |
|-------------------------------|------------|-----------------|-----------------------------|------------------|---------------------------------|-----------------|-----------------------|----------------|-----------------------------|------------------|------------------|--------------|----------------|----------------------------|-------|
| | | | Equip-ment type | No. of fix-tures | No. of non-oper-ating fix-tures | kW per fix-ture | kW per space or usage | Control device | Equip-ment type | No. of fix-tures | kW per fix-tures | kW per space | Control device | | |
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| Totals for Page or Usage Type | | | | | | | | | | | | | | | |
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one set of tables by space location and one set by usage group

Table Completed By:

one set of tables by space location and one set by usage type

Table LE3
Post Installation

Results of Operating Hours Survey and Savings Result

Site Name:

Date of Table:

Bidder Name:

Table Completed By:

Provide documentation on survey results

| Usage area type | Total number samples | Data of survey from--to | Total kW saved | Average Operating Hours | | | | | | Annual kWh saved | Peak demand savings, kW |
|-----------------|----------------------|-------------------------|----------------|-------------------------|------------------|-----------------|------------------|-----------------|-------|------------------|-------------------------|
| | | | | Summer peak | Summer part peak | Summer off peak | Winter part peak | Winter off peak | Total | | |
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Table LE4
Annual Report

Results of Annual Operating Hours Survey and Savings Result

Site Name:

Date of Table:

Bidder Name:

Table Completed By:

Provide documentation on survey results

| Usage area type | Total number samples | Data of survey from--to | Total kW saved | Average Operating Hours | | | | | | Annual kWh saved | Peak demand savings, kW |
|-----------------|----------------------|-------------------------|----------------|-------------------------|------------------|-----------------|------------------|-----------------|-------|------------------|-------------------------|
| | | | | Summer peak | Summer part peak | Summer off peak | Winter part peak | Winter off peak | Total | | |
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Table LC1
Pre-Installation
Lighting Equipment Expected to be Installed

Site Name:

Date of Table:

Bidder Name:

Table Completed By:

| Space ID | Circuit ID | Usage area type | Existing Lighting Equipment | | | | | | Proposed Lighting Equipment | | Notes |
|-------------------------------|------------|-----------------|-----------------------------|-----------------|-------------------------------|----------------|-----------------------|--------------------------|-----------------------------|---------------------|-------|
| | | | Equipment type | No. of fixtures | No. of non-operating fixtures | kW per fixture | kW per space or usage | Existing control device? | New control device? | Control device type | |
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| Totals for page or usage type | | | | | | | | | | | |
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one set of tables by space location and one set by usage group

provide operating hours estimates (annual and peak-period) by usage area in separate table

Table LC2
Post-Installation
Actual Lighting Equipment Replaced and Installed

Site Name:

Date of Table:

Bidder Name:

Table Completed By:

| Space ID | Circuit ID | Usage area type | Existing Lighting Equipment | | | | | | New Lighting Equipment | | Notes |
|-------------------------------|------------|-----------------|-----------------------------|-----------------|-------------------------------|----------------|-----------------------|--------------------------|------------------------|---------------------|-------|
| | | | Equipment type | No. of fixtures | No. of non-operating fixtures | kW per fixture | kW per space or usage | Existing control device? | New control device? | Control device type | |
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| Totals for page or usage type | | | | | | | | | | | |
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Table LC3
Pre-Installation
Results of Operating Hours Survey

Site Name:

Date of Table:

Bidder Name:

Table Completed By:

Provide documentation on survey results

[illegible]

Table LC5
Annual Report
Results of Operating Hours Survey and Savings
Results

Site Name:

Date of Table:

Bidder Name:

Table Completed By:

Provide documentation on survey results

Savings based on difference in operating hours from Table LC3

| Usage area type | Total number sampled | Dates of survey | | Total connected kW | Average Operating Hours: Post-Installation | | | | | | Annual kWh saved | Peak demand savings, kW |
|-----------------|----------------------|-----------------|----|--------------------|--|------------------|-----------------|------------------|-----------------|--------------|------------------|-------------------------|
| | | From | To | | Summer peak | Summer part peak | Summer off peak | Winter part peak | Winter off peak | Total Annual | | |
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**Table M1: Motor Survey
Pre- and Post-Installation Data**

Complete for all motors

| | |
|--------------------|--|
| Contractor Name: | |
| Site Name: | |
| Motor Location: | |
| Motor Application: | |

| | complete during pre-installation | complete during post-installation |
|--------------------------------|----------------------------------|-----------------------------------|
| Item | Baseline | High-Efficiency |
| Motor ID No. | | |
| Table Completed By | | |
| Date of Table | | |
| Nameplate Available (yes/no) | | |
| Manufacturer | | |
| Model No. | | |
| Serial No. | | |
| Service Factor | | |
| Enclosure Type | | |
| Full Load HP | | |
| Volts | | |
| Phase and Hz | | |
| Full Load Amperes | | |
| Full Load Speed (RPM) | | |
| Synchronous Speed (RPM) | | |
| Nominal Efficiency | | |
| Load Served by Motor | | |
| Summer Weekday Operating Hours | | |
| Summer Weekend Operating Hours | | |
| Winter Weekday Operating Hours | | |
| Winter Weekend Operating Hours | | |
| Annual Operating Hours | | |
| Other | | |

**Table M2: Spot Metered Values
Pre- and Post-Installation Data**

Complete for all motors

| | |
|--------------------|--|
| Contractor Name: | |
| Site Name: | |
| Motor Location: | |
| Motor Application: | |

| | pre-installation | post-installation |
|---------------------------|------------------|-------------------|
| Item | Baseline | High-Efficiency |
| Motor ID No. | | |
| Table Completed By | | |
| Date and Time of Readings | | |
| Instantaneous Volts | | |
| Instantaneous Amps | | |
| Instantaneous kW | | |
| Power Factor | | |
| Temp. of Working Fluid | | |
| Location of Temp. Sensor | | |
| Meter Model No. | | |
| Meter Serial No. | | |

**Table M3: Short-Term Metering Results
Pre- and Post-Installation Data**

Complete for each motor in approved sample

| | |
|---------------------|--|
| Contractor Name: | |
| Site Name: | |
| Motor Location: | |
| Motor Application: | |
| Date of Table: | |
| Table Completed By: | |

| Item | pre-installation | | post-installation |
|---|-------------------------|---------------|-------------------------|
| | Baseline | | High-Efficiency |
| Motor ID No. | | | |
| Date and Time Initiated | | | |
| Date and Time Completed | | | |
| Data-Logger Model No. | | | |
| Data-Logger Serial No. | | | |
| Instantaneous Amps (spot meter) Table M2 | | | |
| Normalizing Factor | | | |
| No. of non-zero observations | | | |
| No. of obs. within +/-10% | | | |
| % of obs. within +/-10% | | | |
| Meter Serial No. | | | |
| | Average operating hours | Maximum hours | Average operating hours |
| Summer peak hours | | 774 | |
| Summer partial peak hours | | 903 | |
| Summer off hours | | 2739 | |
| Winter partial peak hours | | 1612 | |
| Winter off hours | | 2732 | |
| Total annual hours | | 8760 | |

Table M4: First Year Sample Selection and Results

To be completed for each unique application.

| | |
|---------------------|--|
| Contractor Name: | |
| Site Name: | |
| Date of Table: | |
| Table Completed By: | |

| | |
|-------------------|--|
| Application Name: | |
|-------------------|--|

| Item | Value |
|---|-------|
| ID Nos. of motors serving application | |
| Required sample size | |
| ID Nos. of motors in sample | |
| Average normalizing factor | |
| Average summer peak operating hours | |
| Average summer partial peak operating hours | |
| Average summer off peak operating hours | |
| Average winter partial peak operating hours | |
| Average winter off peak operating hours | |
| Average total annual operating hours | |

**Table M5: Motor Calculations
Post-Installation (First Year) Results**

Complete for each motor

| | |
|---------------------|--|
| Contractor Name: | |
| Site Name: | |
| Motor Location: | |
| Motor Application: | |
| Date of Table: | |
| Table Completed By: | |

| Item | Baseline | High Efficiency |
|--|----------|-----------------|
| Motor ID No. | | |
| Normalized Demand (kW) | | |
| kW Input at Rated Load | | |
| Load Factor | | |
| Normalized kW Savings | | |
| Summer Peak Period kWh Savings | | |
| Summer Partial Peak Period kWh Savings | | |
| Summer Off Peak Period kWh Savings | | |
| Winter Partial Peak Period kWh Savings | | |
| Winter Off Peak Period kWh Savings | | |
| Total Annual kWh Savings | | |

D

Appendix D: Sampling Guidelines

D.1 Introduction

This appendix introduces the statistical background, theory, and formulas used to calculate sample sizes for monitoring purposes. It has been included for sampling designs that may be required for both lighting and non-lighting projects

This part provides guidelines for the procedures to follow to draw a sample for equipment monitoring. The guidelines are applicable to projects such as lighting retrofits and energy-efficient motor replacements, in which a large number of similar pieces of equipment are affected by the same type of ECM. The sampling guidelines are designed to help the ESCO and the federal agency determine the number of sample points that should be monitored to provide a reliable estimate of parameters such as annual energy savings or hours of operation.

The purpose of monitoring a sample of equipment is twofold:

1. To measure operating patterns or other equipment characteristics used to estimate energy savings or other key parameters for the population from which the sample is drawn
2. To minimize monitoring costs while maintaining specified requirements for the reliability of the estimates

This information can be used to prepare project-specific M&V plans. This part includes 10 topics as follows:

- Part 2 states the general approach.
- Part 3 presents two sampling options.
- Part 4 explains the terminology used in the guidelines.
- Part 5 identifies the assumptions used in the sampling options.
- Part 6 presents the steps involved in calculating sample size.
- Part 7 discusses sample selection.
- Part 8 discusses verification of sample reliability and supplemental sampling.

- Part 9 presents a lighting retrofit example using both sampling options.
- Part 10 summarizes the purpose of sampling.

D.2 General Approach

The sampling techniques in this section describe the procedures for selecting a properly sized random sample of equipment for monitoring factors such as operating hours. The measurements, taken from a sample of equipment, can then be used to estimate operating hours (which are used to calculate energy savings) for the entire population.

A successful sample will be sufficiently representative of the population to enable one to draw reliable inferences about the population as a whole. The reliability with which the sample-based estimate reflects the true population is based on specified statistical criteria, such as the confidence interval and precision level, used in the sample design.

The reliability of a sample-based estimate can be computed only after the metered data have been gathered. Before collecting the data, one cannot state the level of reliability that a given sample size will yield. However, one can compute the sample size that is expected to be sufficient to achieve a specified reliability level. This is done by using projections of certain values and criteria in the sample size calculations. If the projections are too conservative, the estimate will exceed the reliability requirements. If these projections prove to be overly optimistic, then the reliability of the estimates will fall short of the requirements, requiring additional data collection to achieve the specified reliability level. This method of using projections to calculate the necessary sample size is the one adopted for these guidelines.

The proposed sampling approaches consist of grouping the population of the equipment that is affected by the ECM's at the project site into "usage groups" from which samples are drawn. Usage groups are subsets of the entire population of affected equipment at the project site that have similar operating characteristics. Combining the affected equipment into homogeneous groups reduces the sample size required to obtain a reliable estimate. The proper designation of usage groups is critical for maintaining small sample sizes while still obtaining statistically valid results within specified confidence bounds.

In the first year of monitoring, the ESCO will use estimates of the average value and variability for key variables, e.g., operating hours of equipment for lighting projects in each usage group, in order to calculate the sample size required to achieve an estimate of the annual energy savings with the specified level of reliability. The ESCO will select sample points in each usage group randomly, as is consistent with statistical practice.

After the required monitoring is performed on the sample of equipment, the ESCO will estimate the annual energy savings and compute the reliability of that estimate using metered data from the sample. If the reliability of the sample-based estimate falls short of the requirements of these guidelines, the ESCO will need to meter a

larger sample of equipment to achieve the necessary reliability requirements in the subsequent year.

In subsequent years of monitoring, the ESCO will use the results for average operating hours and their variances from the previous year's monitoring to calculate the necessary sample sizes. The formulas for calculating the variances based on the previous year's sample are presented in part D.6.

The perspective of this appendix is that a typical performance contracting arrangement, under the ESPC program, will be one in which the ESCO is responsible for developing a detailed equipment inventory and sampling plan, conducting the metering, and analyzing savings. In contrast, the federal agency reviews and approves each step. Under some arrangements, the federal agency could develop the equipment inventory and sampling plan for the ESCO to follow. In that case, the federal agency would need to complete the tasks in this section that are currently assigned to the ESCO.

D.3 Sampling Options

Two sampling techniques discussed in these guidelines include:¹

1. **Building Level Sampling** using stratified random sampling at the building level
2. **Usage Group Sampling** using simple random sampling at the usage group level, over multiple buildings.

D.3.1 Building Level Sampling

This approach includes guidelines for calculating sample size and allocating the sample across usage groups designed to achieve a specified level of precision for the savings estimate *for a single building*. The approach is based on an optimal allocation of sample points across the usage groups based on expected energy savings. This approach may be applied to a project with only one building, but has the advantage of reducing the overall number of required samples compared to usage group sampling.

D.3.2 Usage Group Sampling

A simple random sampling approach applies the precision criteria to *each usage group within one or more buildings*. This can lead to a higher-than-needed precision level for a single building. The advantages of this approach are (a) it is easy to implement, given a specified sample size table based on equipment population size; and (b) it permits sampling across buildings that are similar, are operated in the same manner, and have the same usage groups.

1. Schiller Associates developed these methodologies for various utility performance contracting programs in collaboration with Dr. Andrew Goett of AAG and Associates and Dr. M. Sami Khawaja of Quantec.

The key to the success of either of these approaches is that the ESCO properly designate usage groups.

D.4 Definitions

The guidelines presented here use certain terminology and notations that are defined as follows.

Last Point of Control (LPC). The last point of control (LPC) is defined as the portion of an electrical circuit that serves a set of equipment that is controlled on a single switch. As a result, all of the fixtures or pieces of equipment on that LPC are typically operated the same number of hours per year. For metering purposes, it is assumed that measurements taken of a single light fixture or piece of equipment on an LPC captures the operating hours for all of the equipment served on the same circuit. (Minor exceptions such as differences due to burnt-out bulbs and the like are ignored for these calculations.)

An example of an LPC would be a set of lighting fixtures in a room that operates on a single switch. If there were two separate switches controlling different groups of fixtures in the room, each one would constitute an LPC for the metering purposes. In the formulas presented later, the total number of LPCs in the project or building is denoted by the population term N .

Usage Group. A usage group is a subset of the whole population of affected equipment at the project site. Usage groups are designated for similar types of equipment, similar areas, or with applications that have similar operating characteristics. The designation of usage groups is based on equipment application and operating characteristics. This grouping technique subdivides a large group into smaller groups that are more homogeneous and thus reduces the variance of the projected operating hours in each group.² By using building-level sampling techniques, the number of LPCs that must be monitored to obtain an estimate with a given level of reliability is minimized. In the formulas presented later, usage groups are indexed by k . For example, the total number of LPCs in the usage group k is denoted by the term N_k .

Usage groups are not appropriately designated if they combine different functional groups with different operating patterns (e.g., offices and closets), lump smaller usage groups together (e.g., closets, storage, and utility rooms), or lump groups based on total annual hours but not operating function and pattern (e.g., offices and commons).

Project Site. A project site is any number of connected buildings. A project is the installation of measures at a project site

2. Care must be taken when designating usage groups, since too few groupings may result in higher variances in operating hours and require a larger sample for each usage group in subsequent monitoring periods. If there are too many groupings with too few points, the estimate of variance used for determining sample size in subsequent years will be poor and possibly lead to under-sampling.

Aggregation of Project Sites. For aggregation of project sites (i.e., multiple buildings) into a single project-specific M&V plan, all the project sites must have the same ESCO, measures, occupancy schedule, functional use, and energy consumption patterns.

Sample. The sample is the number of points (LPCs) that are monitored in each year. This sample must be drawn at random from the population of LPCs in each usage group, so that each LPC in a given usage group has the same likelihood of being selected to be monitored. The total sample size is denoted by n , and the sample in each usage group is n_k . The percentage of circuits sampled in a given usage group is denoted by n_k/N_k .

Sample Mean. The purpose of monitoring a sample of equipment or circuits is to estimate the mean or average value for one or more variables. For example, a typical objective of monitoring is to estimate the average hours of operation per year for the equipment that has been retrofitted with ECMs. The estimate of operating hours from the sample is used, in turn, to estimate the total energy savings.

Measures of Variability. The variance, standard deviation, standard error, and coefficient of variation are measures of the variability of the values of the variable of interest (e.g., hours of operation) around the average. If the values are all clustered very close together, these measures are small. In the formulas presented later section, the variance is denoted by $S^2()$. The standard deviation is $SD()$, the standard error is $SE()$, and the coefficient of variation is $c.v.()$. ($c.v.() = SD()/\text{mean}()$)

Reliability Level. The reliability of a sample refers to the confidence with which one can state that the estimate produced by the sample falls within a specified range of the true value in the population. Any time an estimate of some variable such as average operating hours is based on measurements from a sample (rather than the entire population), the estimate typically will differ from the true value for the population. This difference will vary from sample to sample, so that one cannot state with certainty the magnitude of any error in the estimate caused by using a sample. However, one can state the likelihood or probability that the estimate falls within some specified range of the true value for the population.

For example, one may be able to state that the probability is 95% that an estimate from a given sample falls within 100 hours of the true average number of operating hours per year. This means that if one drew 1,000 different independent samples, 95% of them would produce estimates within 100 hours of the population average. The probability (95%) is referred to as the confidence level. The specified range (100 hours) is the level of precision. This precision can be stated in absolute terms (± 100 hours) or percentage terms ($\pm 10\%$). By increasing the size of the sample used to produce the estimate, one can increase the reliability of the estimate (i.e., increase the confidence level, narrow the precision, or both).

Projected versus Estimated Total Savings and Its Variability. In the discussion below, the distinction is made between projected versus estimated values of the total savings and its variability. In order to calculate the sample size expected to achieve a

specified level of reliability, one must make a prior *projection* of the total value and its variability. These projections are the values that one anticipates obtaining from the measurements on the sample.

In the first year, these projections may be based on the results of other studies or they may be based on subjective judgments. Once the measurements are taken, the total savings and its variability can be *estimated* based on the actual sample data. These estimates may be used in the second and subsequent years as projections for calculating the sample size of additional metering.

Table D.1: List of Variables and Definitions

| Variable | Definition |
|------------------------------------|---|
| N | Population of LPCs |
| k | Usage group |
| n | Total sample size |
| N_k | Population of LPCs in usage group k |
| n_k | Sample size in usage group k |
| n_k/N_k | Percentage of points sampled |
| S | Standard deviation |
| SE | Standard error |
| c.v. | Coefficient of variation |
| i | Sample point (from metering) |
| P | Metering precision |
| Z | Z-statistic for determining confidence interval |

D.5 Assumptions

These guidelines for determining sample size are based on several key assumptions and criteria:

Parameters to be Measured. Annual energy and peak demand savings are the critical parameters to be estimated for a performance contract. For the sampling of equipment in lighting and motor replacement projects, the key variable to be measured is operating hours per year (or operating hours during a defined peak period).³ The changes in the number of units and watts are assumed to be known without error for the entire population of affected equipment. Thus, the accuracy of the average operating-hour estimate of the affected equipment at the project site

based on the sample is directly related to the accuracy level for the estimate of energy savings.

Sample Design Variable. For building level sampling, the variable that will be used to determine the required sample size is the annual electricity savings for the entire building or building in which the lighting or meter efficiency measures are installed. As a first-order approximation, the annual savings are equal to:

$$\text{Savings} = \sum_k \Delta \text{watts}_k \times \overline{\text{OpHours}}_k$$

where:

- Savings = the annual energy savings for the building⁴
- Δwatts_k = the total change in wattage in usage group k
- $\overline{\text{OpHours}}_k$ = the average hours of operation per year of the equipment in usage group k .

Changes in Wattage. As part of the installation of ECMs, the ESCO records the change in wattage due to the replacement. As a result, the total change in wattage is known with certainty for all of the affected equipment in each usage group in the building.

Projection of Operating Hours. The ESCO makes a projection of the average operating hours of the affected equipment in each usage group. Before the first year of monitoring, this may be a subjective judgment based on (a) the building operator's knowledge of how the affected equipment is typically used in each area; (b) a prior study of similar areas; or (c) a federal-agency-approved, pre-installation metering of a small sample in each usage group. After the first year, the metered results from monitoring in the previous year will be used to determine the present-year sample size.

Reliability Level. The sample size needs to be sufficiently large to estimate the average annual operating hours within acceptable reliability requirements. What constitutes acceptable reliability is subject to discussion and negotiation. For example, utility DSM programs often use 90% confidence at 10% precision (90/10) or 80% confidence at 20% precision (80/20). (Both criteria are applied at the usage group level.) Which criteria are used depends on how reliable and accurate the utility company would like the savings estimates. What agencies and ESCOs need to realize is that increasing the reliability and accuracy of the savings estimates significantly increases

3. The formulas presented for calculating the necessary sample size are based on the assumption that the objective of the measurements is to estimate annual energy savings. If the objective is to estimate average kW reduction during the peak period, then the formulas would need to be modified by substituting a kWh variable with a kW variable.

4. For purposes of calculating sample size, secondary effects, such as reduced internal loads caused by more efficient equipment, are ignored.

the effort required. Improving the precision from 20% to 10% will increase sample size (and M&V cost!) fourfold. Selecting the appropriate sampling criteria requires balancing accuracy requirements with M&V costs. Building-level sampling attempts to maximize accuracy while minimizing total sample size and M&V cost.

Oversampling. The initial sample size should be increased to compensate for potential reductions in the final usable sample due to equipment failure or loss. *Suggested* guidelines are that the sample size be increased by 10% above the required amount.

D.6 Steps in Calculating Sample Size

The ESCO will calculate the number of pieces of equipment to be metered according the following procedure:

1. **Compiling ECM Information.** As part of the installation of ECMs, the ESCO will compile the following information for the equipment affected by the measures:
 - *Number of LPCs.* The ESCO will identify and document the LPCs that are affected by the installation of ECMs. This would be in the form of an equipment inventory survey in which each line in the survey represents an LPC that includes descriptions of affected and proposed ECM nameplate data and quantity as well as location information.
 - *Total Change in Wattage.* Using the equipment inventory survey, the ESCO should tabulate the total change in wattage of the affected equipment by usage group.
 - *Projected Hours of Operation.* The ESCO will project the average hours of operation of the equipment. This projection, which is distinguished from the estimate based on the monitoring, will be used solely for calculating the size and distribution of the sample required for monitoring. In the first year, it should be based on the experience of the building operator, on the operation of the affected equipment or even some preliminary monitoring. After the first year of monitoring, the ESCO should use the estimate obtained from metering in the prior year to compute the sample size. If the ESCO expects that the equipment will be used in a significantly different manner in the current year than it was in the previous year, the estimate may be adjusted to reflect this, but only after the federal agency's review and approval.
 - *Expected Savings.* The ESCO will project the expected annual savings from the ECMs installed in the building. This projection will be consistent with the change in wattage and projected hours of operation.
2. **Designating Usage Groups.** The ESCO will assign each LPC to a usage group based on similarities in equipment and operating characteristics as follows:
 - Area type (e.g., office, hallway, bathroom)
 - Annual operating hours

- Timing of the operating hours
- Variability of operating hours
- Similar functional use.

For the federal agency's project, a usage group is defined by equipment in the same area type for which the annual operating hours cluster around a specific estimate. At the same time, ESCOs should avoid designating usage groups with populations that will yield less than 10 points.

Sources of information on operating characteristics, other than monitoring, used in defining usage groups include the following: (a) operating schedules that provide information on energy consumption or hours of operation and (b) type of application or location that provides information on how and when equipment (e.g., fixtures or motors) is operated.

Examples of standard usage groups for fan motors with similar operating characteristics are HVAC ventilation supply fans, return fans, and exhaust fans. Examples of standard usage groups for lighting projects are fixtures with similar operating characteristics in offices, laboratories, hallways, stairwells, common areas, perimeters, and storage areas.

In some instances, area type alone may be insufficient to designate usage groups. Usage groups may need to be further subdivided if an area type is inherently variable because area occupants have very different characteristics. For example, some laboratories may have longer operating hours than others and should be subdivided, if information is available that predicts the operating hours (e.g., computer laboratory hours are 8 hours per day while agriculture laboratory hours are 4 hours per day).

Usage groups will typically be defined for the population on a building-by-building basis. However, under special circumstances, for some projects it may be reasonable to determine sample sizes across a number of buildings with similar usage areas. For example, if an ESCO is conducting lighting retrofits in barracks, then the usage groups of common sleeping areas, private sleeping areas, washrooms, etc., may be totaled for all the barracks. These values can be used to determine total population size for each usage group (assuming the usage group level sampling option is used). In applying the Usage Group Sampling approach, the samples would be selected from all the barracks. This would result in fewer monitoring points than if each building were considered separately.

- 3. Establishing Coefficient of Variation.** In the first year of monitoring, the projection of the coefficient of variation is typically drawn from other studies that have metered the operation of buildings with similar operating characteristics. However, under this guideline, the ESCO must use a coefficient of variation in each group of 0.5 as a default value. This assumption requires proper designation of homogeneous usage groups (where, in a given usage group, each point's projected operating hours vary no more than two standard deviations from the

mean). Coefficients of variation from metered data are used in subsequent years to determine the sample size.

After the first year of monitoring, the coefficient of variation for each usage group can be projected from the results of the metering in the previous year. This is obtained by using the sample-based estimates of average hours of operation and of the standard deviation (the square root of the variance) in the equation.

- 4. Calculating Sample Sizes.** Using the information above, the ESCO will calculate the total sample size and its allocation across usage groups.

Option 1: Building Level Sampling

Option 1 produces a sample size expected to estimate the average hours of operation with the minimum number of samples. The steps and formulas needed to compute the smallest sample size that meets the required precision and confidence are the following:

Total Sample Size. The total sample size is given by the following formula:

$$(D.1) \quad n = \frac{\left(\sum_k (\Delta \text{watts}_k \times [\text{c.v.}(\text{projHrs}_k)] \times \overline{\text{projHrs}_k}) \right)^2}{\left(\frac{P \times \text{ExpSavings}}{Z} \right)^2 + \sum_k \frac{(\Delta \text{watts}_k \times [\text{c.v.}(\text{projHrs}_k)] \times \overline{\text{projHrs}_k})^2}{N_k}}$$

where:

N = Total sample size

N_k = Total number of LPCs in usage group k

ExpSavings = The projected annual energy savings for the building

Δwatts_k = The total change in wattage in the usage group denoted by k

$\overline{\text{projHrs}_k}$ = The projected average hours of operation per year of the equipment in usage group k

$\text{c.v.}(\text{projHrs}_k)$ = The coefficient of variation of operating hours in usage group k , which is assumed to be 0.5 for the first year of monitoring

P = Precision required, typically 10% or 20%

Z = Z-statistic, 1.645 for 90% confidence, 1.282 for 80% confidence.

Allocation of Sample by Usage Group. The percentage of the total sample n that is assigned to usage group k is as follows:

$$(D.2) \quad n_k = \left[\frac{\Delta \text{watts}_k \times [\text{c.v.}(\text{projHrs}_k)] \times \overline{\text{projHrs}_k}}{\sum_k \Delta \text{watts}_k \times [\text{c.v.}(\text{projHrs}_k)] \times \overline{\text{projHrs}_k}} \right] \times n$$

where:

n_k = The sample size in usage group k ; other terms are as defined above.

In the first year, the steps for computing the sample size and allocation are:

- Using (D.1), calculate the total sample size n based on the information on the change in wattage, projected hours of operation, and coefficient of variation by usage group.
- Calculate the percentage of n to be allocated to each usage group (n_k) based on the formula in equation (D.2), rounding the result up to the nearest whole number.

It is not possible to determine the reduction in sample size that building-level sampling provides compared to usage-group sampling without specific project information, but it can be significant if one usage group contributes significantly to the total uncertainty.

Option 2: Usage Group Sampling

Option 2 produces a sample size expected to estimate the average hours of operation with the required accuracy and confidence for each usage group in the building (or buildings). The steps and necessary formulas for computing the smallest sample size necessary to achieve these levels of precision and statistical confidence are the following:

Sample Size per Usage Group. The total sample size per usage group is given by the following formula:

$$(D.3) \quad n_k = \frac{Z^2 \times [\text{c.v.}(\text{projHrs})]^2}{P^2}$$

where:

Z = Z-statistic, 1.645 for 90% confidence, 1.282 for 80% confidence

P = Precision required, typically 10% or 20%.

When the population under study is relatively small, a finite population correction factor should be employed. Typically, this will be required when the population is less than 100 to 500. The finite population adjustment equation is as follows, with n^* being the new sample size corrected for population size:

$$(D.4) \quad n^* = \frac{Nn}{n + N}$$

In the first year, the step for computing the sample size and allocation are as follows:

- Using equation (D.3), calculate the total sample size n based on the confidence and precision requirements and coefficient of variation for each usage group.
- Correct the sample size n for each group by using equation (D.4). It is suggested that the sample size be increased by 10% and then rounded up to the next integer.

Table D.2 illustrates the effect of confidence interval and precision on sample size. Required sample sizes are shown for different group population sizes at three different confidence and precision criteria: 80/20, 90/20, and 90/10. For an infinite population size, increasing confidence from 80% to 90% increases sample size by 54%. Halving the uncertainty from 20% to 10% precision requires four times as many samples per usage group. Oversampling is not included in this sample size table. ESCOs who use this table should increase sample size by 10% to account for logger failures and loss.

Table D.2: First-Year Sample Size Table Based on Usage Group Sampling (no oversampling)

| Precision | 20% | 20% | 10% |
|--------------------|--------------------|-------|-------|
| Confidence | 80% | 90% | 90% |
| Z-Statistic | 1.282 | 1.645 | 1.645 |
| Population Size, N | Sample Size, n^* | | |
| 4 | 3 | 4 | 4 |
| 8 | 5 | 6 | 8 |
| 12 | 6 | 8 | 11 |
| 16 | 7 | 9 | 13 |
| 20 | 8 | 10 | 16 |
| 25 | 8 | 11 | 19 |
| 30 | 9 | 11 | 21 |

| | | | |
|--------------------|-----------------|-------|-------|
| Precision | 20% | 20% | 10% |
| Confidence | 80% | 90% | 90% |
| Z-Statistic | 1.282 | 1.645 | 1.645 |
| Population Size, N | Sample Size, n* | | |
| 35 | 9 | 12 | 24 |
| 40 | 9 | 12 | 26 |
| 45 | 9 | 13 | 28 |
| 50 | 10 | 13 | 29 |
| 60 | 10 | 14 | 32 |
| 70 | 10 | 14 | 35 |
| 80 | 10 | 15 | 37 |
| 90 | 10 | 15 | 39 |
| 100 | 10 | 15 | 41 |
| 125 | 11 | 15 | 45 |
| 150 | 11 | 16 | 47 |
| 175 | 11 | 16 | 49 |
| 200 | 11 | 16 | 51 |
| 300 | 11 | 17 | 56 |
| 400 | 11 | 17 | 59 |
| 500 | 11 | 17 | 60 |
| infinite | 11 | 17 | 68 |

Selecting the appropriate sampling criteria depends on the acceptable uncertainty and the M&V budget. Much of the M&V cost is allocated to installing and removing loggers, so increasing sample size to improve reliability directly increases the M&V cost. Finding the most cost-effective sampling criteria is beyond the scope of this discussion, but the general idea is to avoid paying more for M&V than the value of the information returned.

D.7 Sample Selection and Equipment Metering

Given the values of n_k , the samples in each usage group should be drawn at random, so that each LPC has an equal probability of being selected.⁵ To allow for possible

5. Random selection of monitoring points is critical to avoid bias in the sample. Spreadsheet or other computer software should be used to generate a list of random numbers that may be used to place loggers on a given LPC.

attrition due to metering equipment failures and the like, the ESCO should monitor at least 10% more cases in each usage group than are required to meet the reliability requirement (i.e., the number of LPCs upon which meters are installed should be at least 110% of n_k).

The metering period should be selected so that it is representative of equipment usage during the year. The metering should not be performed during periods with major holidays or when a significant portion of the building occupants are on vacation.

If there is reason to believe that there are significant seasonal variations in the average hours of operation of the equipment, the ESCO should conduct monitoring during different seasons. The ESCO should select the periods in each season that are representative of equipment usage. The average annual operating hours will be estimated by taking an average of the seasonal values, weighted by the number of months in each season.

D.8 Verification of Sample Reliability and Supplemental Sampling

After metering has been completed, the data will be used to calculate annualized values for operating hours or another variable for which measurements have been taken. For example, if the equipment was metered for 21 days, then the estimate of annual operating hours would be the 21-typical-day total times 365/21 (365 days/year, 21 days monitored). The ESCO needs to ensure that the 21-day monitoring period does not include holidays that might bias the results.

Annualized values of operating hours will be used to estimate the total annual energy savings for the building and the standard error. These will be used to determine whether the reliability of the sample-based estimate meets the accuracy requirement. If the reliability of the estimate fails to meet the required level of confidence or precision, the ESCO will be required to meter a larger sample of equipment to increase reliability in the following year. The size of this sample will be determined by substituting the metered estimates for the projected values and computing the necessary n and n_k . The difference between the new values of n and n_k and the old values is the supplemental sample size. A description of the procedure to use is presented in the next section.

D.8.1 Building-Level Verification

Estimate the total savings and the standard error of the total according to the following formulas:

$$(D.5) \quad \text{Savings} = \sum_k \Delta \text{watts}_k \times \overline{\text{ActHrs}_k}$$

$$(D.6) \quad \text{SE}(\text{Savings}) = \sqrt{\sum_k (\Delta \text{watts}_k)^2 \times S^2(\text{ActHrs}_k)}$$

where:

- $\overline{\text{ActHrs}_k}$ = the metered average operating hours in usage group k
- $S^2(\text{ActHrs}_k) = \sum_i \frac{(\text{ActHrs}_{i,k} - \overline{\text{ActHrs}_k})^2}{n_k - 1}$ = the estimated variance of operating hours in usage group k , based on the metered observations i .

Using the estimates based on the metered data, the ESCO will determine whether they meet this reliability requirement (for 90/10):

$$(D.7) \quad \text{SE}(\text{Savings}) \leq \frac{(0.1 \times \text{Savings})}{1.645}$$

For other metering criteria, substitute the appropriate precision and Z-statistic in the previous equation.

D.8.2 Usage-Group-Level Verification

In the usage group sampling approach, the standard error test is conducted separately on (a) each usage group's sample-based estimate rather than cumulatively, and (b) hours of operation rather than energy savings.

Calculate the standard error of the actual metered operating hours:

$$\text{SD}(\text{ActHrs}_{i,k}) = \sqrt{\sum_i \frac{(\text{ActHrs}_{i,k} - \overline{\text{ActHrs}_k})^2}{n_k - 1}}$$

$$(D.8) \quad SE(\text{ActHrs}_{i,k}) = SD_k / (\sqrt{n_k})$$

For each usage group, test whether the sample-based estimates meet the reliability requirement (for 90/10):

$$(D.9) \quad SE(\text{ActHrs}_k) \leq \frac{(0.1 \times \text{ActHrs}_k)}{1.645}$$

If the estimate fails to meet the reliability requirement, the ESCO may be required to meter a supplemental sample of equipment to increase reliability. The size of this sample will be determined by using the measured coefficient of variation *c.v.* to calculate the required sample size n^* . The difference between the new values of n^* and n_k and the old values is the supplemental sample size.

D.9 Lighting Retrofit Example-Application of Sampling Options

The sampling procedures are illustrated by the following example. Suppose that the ESCO is retrofitting lighting fixtures in a large office building and compiles the information shown in Table D3. The agreed-upon sampling criteria for this example are 20% precision at 90% confidence (90/20).

Table D.3: Example Inputs for Calculating the Monitoring Sample

| Usage groups for Building A-1, K | Number of lighting LPCs, N | Total change in wattage (kW), Dkilowatts _k | Projected average hours of operation, projHrs | Expected savings (kWh/year), ExpSavings |
|----------------------------------|----------------------------|---|---|---|
| Offices | 400 | 20.0 | 2,860 | 57,200 |
| Hallways | 600 | 108.0 | 7,488 | 808,704 |
| Meeting rooms | 150 | 67.5 | 1,040 | 70,200 |
| Other | 200 | 60.0 | 2,080 | 124,800 |
| Total | 1,350 | 255.5 | | 1,060,904 |

D.9.1 Application of Building-Level Sampling

The sampling procedure varies with the following measurement cycle:

- First Measurement Period

Using the values shown in Table D.3 in Equation D.1 yields a total sample size of 64. According to Equation D.2, the percentage of sample in each usage group is calculated as shown in Table D.4. After rounding, the total sample increases to 66. Table D.4 also presents the sample sizes adjusted by 10% for oversampling, which is suggested but not required.

- Subsequent Monitoring Periods

In the second and subsequent years, the same procedure will be used to calculate the sample size, with one exception: the values of $\overline{projHrs}_k$ and $c.v.(projHrs_k)$ will be calculated from the data collected in the previous year's sample.

Table D.4: Example Sample Sizes by Usage Group

| Option 1: Building-Level Sampling (90/20) | | | |
|---|-------|-----------------|-------------------------|
| Usage group, K | n_h | n_h (rounded) | $n_h = 10\%$ (rounded)* |
| Offices | 3.4 | 4 | 5 |
| Hallways | 48.1 | 49 | 54 |
| Meeting rooms | 4.2 | 5 | 6 |
| Other | 7.4 | 8 | 9 |
| Total | | 66 | 74 |

*A $c.v.(y) = 0.5$ is the default in the first measurement period; 10% additional sampling has been added to account for missing or malfunctioning loggers or improper usage group designations.

Note that the required total sample size without oversampling (66) is identical to what would be required using usage-group sampling (66 samples, but 16 or 17 samples per group). The difference is that most of the building-level sampling has been concentrated in the hallway group because it represents the largest project savings and is thus the greatest contributor to the total uncertainty. This is a result of assuming a coefficient of variation for all groups of 0.5. In subsequent years, the total sample size and sample allocations will change when measured c.v.s are used.

Suppose that the ESCO obtains useful monitoring data for the required number of sample points and computes the standard errors of the operating hours and the estimated savings for each usage group presented in Table D.5. Using Equation D.6, one finds that the standard error of the total estimated savings is 408,815, which is above the value of 64,493 [$\%precision \times expected\ savings / critical\ Z\text{-statistic}$, or $(0.1 \times 1,060,904) / 1.645$] required to meet the reliability requirement.

Table D.5: Metered Results Based on Building-Level Sampling in the First Performance Period

| Usage group, K | Total changes in wattage, Dkilowatts _k | Monitored average hours of operation, ActHrs | Standard deviation of operating hours, SD(ActHrs) | Estimated savings (kWh/year), EstSavings |
|----------------|---|--|---|--|
| Offices | 20 | 3,400 | 2,380 | 68,000 |
| Hallways | 108 | 7,000 | 3,500 | 756,000 |
| Meeting rooms | 67.5 | 1,400 | 1,000 | 94,500 |
| Other | 60 | 2,500 | 2,200 | 150,000 |
| Total | | | | 1,068,500 |

A revised sample size is calculated from the monitoring data by substituting the measured average hours of operation and the coefficients of variation (the standard deviation of operating hours in each usage group divided by the average) for the previous, projected values. These are used in Equations D.1 and D.2 to calculate a revised total sample size and allocation across usage groups. In this example, the revised rounded total sample size is 98. Table D.6 shows sample size calculations for second-year monitoring.

Table D.6: Revised Sample Requirements Using Building-Level Sampling

| Usage group, K | Actual sample, n | Total change in wattage, Dkilowatts _k | Estimated savings (kWh/yr.), EstSavings | Coefficient of variation (c _v), EstSavings | n _h | New n _h (rounded) |
|----------------|------------------|--|---|--|----------------|------------------------------|
| Offices | 5 | 20 | 68,000 | 0.70 | 6.5 | 8 |
| Hallways | 54 | 408 | 756,000 | 0.50 | 51.59 | 58 |
| Meeting rooms | 6 | 67.5 | 94,500 | 0.71 | 9.21 | 11 |
| Other | 9 | 60 | 150,000 | 0.88 | 18.01 | 21 |
| Total | 74 | | 1,068,500 | | | 98 |

D.9.2 Application of Usage Group Sampling

Usage group sampling is applied when a project includes numerous buildings that are similar in function and layout, are operated in the same manner, and have the same usage groups. This approach allows sampling to be done across similar buildings.

Suppose that the ESCO is retrofitting lighting fixtures in a large office complex containing six buildings that have identical floor plans, similar functions, and identical operating schedules. Usage group sampling is applied to each of the four usage groups that appear in the six buildings, and the sample size is 76 points.

Table D.7: Example Inputs for Calculation of Monitoring Sample for Complex A

| Usage groups for Complex A | Number of lighting LPCs (N) | | | | | | | Sample size (90/20) $n^* + 10\%$ (rounded) |
|----------------------------|-----------------------------|--------------|--------------|--------------|--------------|--------------|--------------|--|
| BUILDING | A-1 | A-2 | A-3 | A-4 | A-5 | A-6 | All | |
| Offices | 400 | 350 | 450 | 440 | 350 | 450 | 2,440 | 19 |
| Hallways | 600 | 550 | 450 | 440 | 550 | 450 | 3,040 | 19 |
| Meeting rooms | 150 | 200 | 200 | 160 | 200 | 200 | 1,110 | 19 |
| Other | 200 | 220 | 180 | 180 | 220 | 180 | 1,180 | 19 |
| Total | 1,350 | 1,320 | 1,280 | 1,220 | 1,320 | 1,280 | 1,770 | 76 |

Note: Sample points (19 for each usage group, as shown above) should be distributed randomly across the sites.

The sampling procedure varies with the following measurement cycle:

- First Monitoring Period:

Using Table D.2 (or Equations D.3 and D.4, assuming $c.v.(projHrs) = 0.5$) to determine the sample size based on number of lighting areas (N) in each usage group, one obtains a total sample size of 76, as shown in Table D.7.

- Subsequent Monitoring Periods:

In the second and subsequent years, the same procedure will be used to calculate the sample size, with one exception: the values of $\overline{projHrs_k}$ and $c.v.(projHrs_k)$ will be calculated from the data collected in the previous year's sample.

Suppose that the ESCO obtains useful metered data for the required number of sample points and computes the standard errors of the actual measured operating hours for each usage group, where the actual values are presented in Table D.8.

Using Equation D.7, one calculates the standard error of the total estimated savings for each usage group; values are shown in Table D.8. For two of the four usage groups, (i.e., hallways and meeting rooms), the actual metered standard error is greater than the allowable amount; thus the reliability requirement is not met for each usage group in the project.

Table D.8: Results Based on Usage Group Sampling in the First Performance Period

| Usage groups for Complex A, K | Number of samples metered, n^* | Actual annual operating hours, $ActHrs_k$ | Standard deviation | Standard error, $SE(ActHrs_k)$ | Allowable error $\frac{(0.2 \times ActHrs_k)}{1.645}$ | Reliability requirement met? |
|-------------------------------|----------------------------------|---|--------------------|--------------------------------|--|------------------------------|
| Offices | 19 | 5,256 | 1,314 | 319 | 639 | Yes |
| Hallways | 19 | 7,008 | 5,605 | 1,360 | 852 | No |
| Meeting rooms | 19 | 2,628 | 1,568 | 382 | 319.5 | No |
| Other | 19 | 1,752 | 701 | 170 | 213 | Yes |
| Total | 76 | | | | | |

A revised sample size is calculated from the metered data by substituting the measured average hours of operation and the coefficients of variation (the standard deviation of operating hours in each usage group divided by the average) for the previous, projected values. These are used in Equations D.3 and D.4 to calculate a revised total sample size and allocation across usage groups. In this example, the revised rounded total sample size is 91. The allocation by usage group is presented in Table D.9.

Table D.9: Revised Sample Requirements Using Usage Group Sampling (Option 2)

| Usage group for Complex A, K | N | n | $ActHrs_k$ | $cv(ActHrs) =$ | New sample size, n_{new} | Adjusted size $n_{new}^* = 10\%$ |
|------------------------------|-------|----|------------|----------------|----------------------------|----------------------------------|
| Offices | 2,440 | 17 | 5,256 | 0.25 | 4 | 5 |
| Hallways | 3,040 | 17 | 7,008 | 0.8 | 43 | 47 |
| Meeting rooms | 1,110 | 17 | 2,628 | 0.6 | 24 | 27 |
| Other | 1,180 | 17 | 1,752 | 0.4 | 11 | 12 |
| Total | 7,770 | 68 | | | | 91 |

D.10 Summary Note

Finally, keep in mind that the purpose of sampling is to monitor a representative sample of points rather than the entire population. The end result is to obtain reliable estimates within a specified precision and statistical confidence. Monitoring the specified number of points (that are calculated from the equations in this appendix) does not necessarily mean the ESCO has complied with the requirements of the guidelines. The ESCO may have improperly designated usage groups, used incorrect sample design assumptions, or selected nonrandom points, all of which may lead to sample-based estimates that are biased and/or unreliable within specified levels. It is critical that the ESCO take care during the initial developmental stages to design a sample that truly reflects the project site.

The federal agency will examine the results of each year's worth of monitoring results of the measured average and variance(s) to establish the sample size in the subsequent performance period.

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